SONIC TEST FOR THE EVALUATION OF STRIPPING RESISTANCE IN COMPACTED BITUMINOUS MIXTURES

MARCH, 1956
No. 11

by

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&
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Joint Highway Research Project

PURDUE UNIVERSITY
LAFAYETTE INDIANA

SONIC TEST FOR EVALUATION OF STRIPPING RESISTANCE

IN COMPACTED BITUMINOUS MIXTURES

TO: K. B. Woods, Director
Joint Highway Research Project

March 13, 1956

File: 2-5-1-1
C-36-8C

FROM: Harold L. Michael, Assistant Director

Attached is a paper entitled, "Sonic Test for Evaluation of Stripping Resistance in Compacted Bituminous Mixtures," by O. B. Andersland, Graduate Assistant, and W. H. Goetz, Research Engineer. This paper was prepared from data obtained by Mr. Andersland and used in the preparation of his thesis for the degree of Master of Science in Civil Engineering.

The paper was presented by Mr. Andersland at the annual meeting of the Association of Asphalt Paving Technologists in Cleveland February 13-15, 1956. The paper was well received and evoked considerable favorable discussion.

Mr. Andersland terminated his services with Purdue University on February 15 and is now employed on the Illinois Test Road, Ottawa, Illinois.

Respectfully submitted,

Harold L. Michael

Harold L. Michael, Assistant Director
Joint Highway Research Project

HLM:cjg

Attachment

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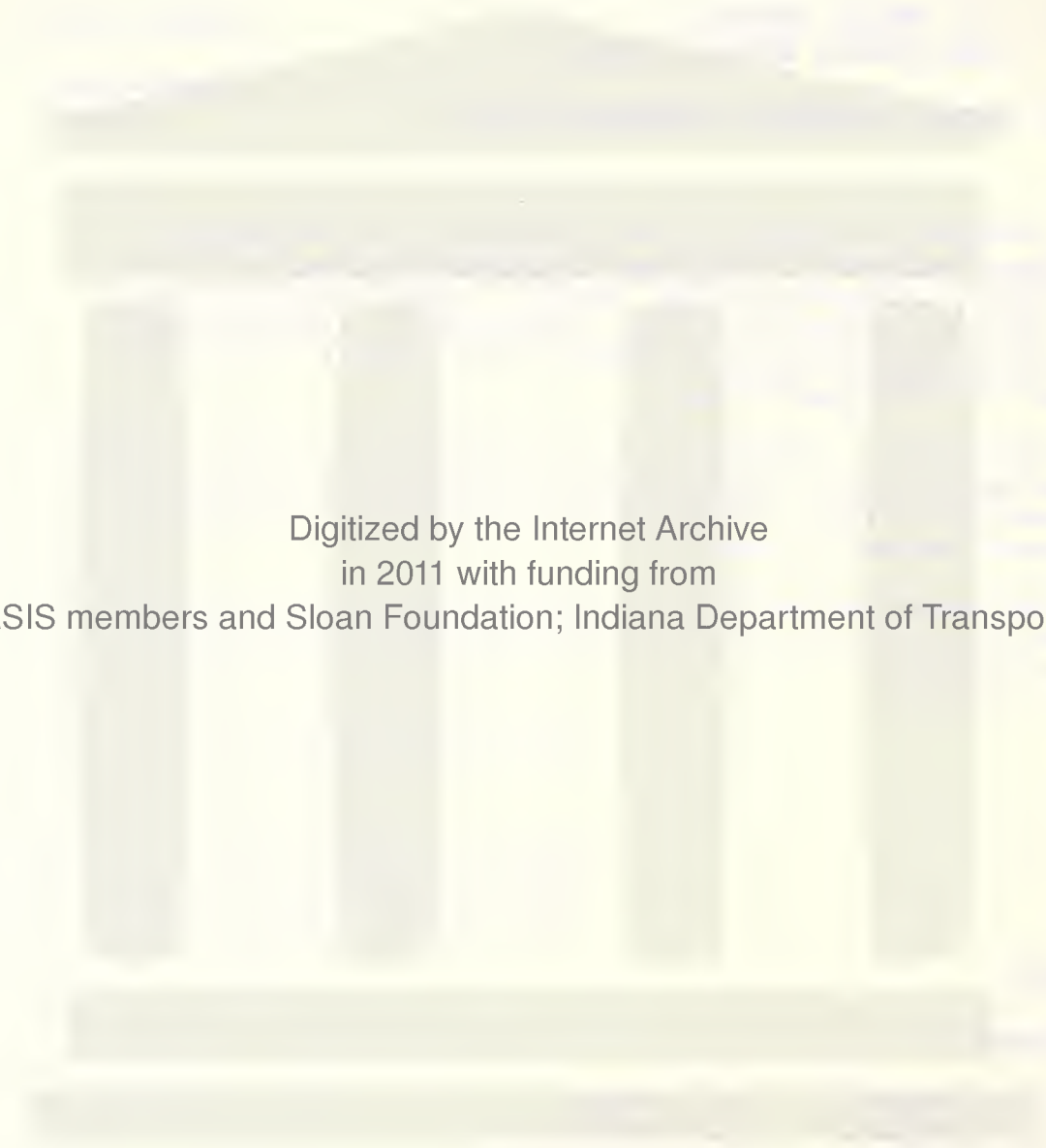

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SONIC TEST FOR EVALUATION OF STRIPPING RESISTANCE IN COMPACTED BITUMINOUS MIXTURES

By

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Presented to the Annual Meeting,

Association of Asphalt Paving Technologists,

February 13-15, 1956, Cleveland, Ohio

SONIC TEST FOR EVALUATION OF STRIPPING RESISTANCE IN COMPACTED BITUMINOUS MIXTURES

O. B. Andersland and W. H. Goetz[1]

INTRODUCTION

Compacted bitumen-aggregate mixtures used for road surfaces show various degrees of deterioration when exposed to water. This deterioration is usually called stripping. Stripping action will cause failure in road surfaces under service conditions because of a loss in strength or stability brought about by a decrease in adhesion between the bituminous material and the aggregate. Failure in adhesion of the bitumen-aggregate mixtures appears to be due to the displacement of the binder by water. Adhesion between the bituminous material and the aggregate arises from their surface properties and is affected by the following factors (1): 1. Surface tension of both the liquid and the solid; 2. Viscosity of the liquid; 3. Surface texture of the solid; 4. Cleanness and freedom from moisture of the solid and liquid surfaces; 5. Porosity of the solid; 6. Absorption of the liquid on the surface of the solid; and 7. Chemical action of the liquid on the solid.

In recent years, many methods for evaluating the resistance to displacement by water of the bitumen in bitumen-aggregate mixtures have been presented. Included among these methods are wash tests and boil tests in which a visual estimation is made of the aggregate area remaining

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coated after prescribed exposure conditions; swell tests in which the amount of swelling of a molded specimen in contact with water is measured; strength tests in which the loss of cohesion resulting from the action of water on compacted bituminous mixtures is obtained; a partition test in which the rating is made by determining the distribution of powered aggregate between water and low viscosity bitumen solution; and numerous other tests.

Two tests commonly used and included in A.S.T.M. standards are "Test for Effect of Water on Cohesion of Compacted Bituminous Mixtures" and "Static Immersion Stripping Resistance Test". The former, frequently called the A.S.T.M. Immersion-Compression Test, shows the detrimental effect of water as a percentage of the original strength that is retained after the immersion period. A disadvantage of this test is the need for three duplicate specimens to give an average value of compressive strength. Variations in the specimens can give inconsistant results. In the latter, frequently called the Static Immersion Stripping Resistance Test, stripping resistance is visually estimated after the water immersion period and expressed as the percentage of the area of the aggregate remaining coated. Pauls and Rex (2) list the disadvantages common to all stripping tests as follows: "First, only one size fraction of the whole aggregate is usually selected for the test. Second, estimation of the extent of stripping is made by visual observation . . . , a method seriously lacking in precision. Third, results of such tests give no indication of the actual degree of adhesion of the bituminous film to the aggregate particle . . . Fourth, and most significant, there is no direct relation between the results obtained by any of the stripping tests and the effects that

will be obtained when the complete bituminous mixture containing the aggregate in question is exposed to the action of water".

Application of the sonic method of testing to compacted bituminous mixtures is quite recent (3) (4) (5). Bawa's (3) work showed that a sonic modulus of elasticity could be obtained for beam specimens using the theory of sonic vibrations. Yong (4) improved the technique for making the beam specimens and also found that the sonic method of test would be a useful tool in determining and following the relative deterioration of bitumen-aggregate mixtures subjected to weathering tests A test temperature of 40°F appeared to be most suited for determination of the sonic modulus. The sonic test method showed several advantages favoring its use (5). First, the determination of a resonant frequency and computation of the modulus of elasticity was relatively easy. Second because the test is non-destructive, it can be applied repeatedly to the same specimen for following a progressive change.

The study on which this paper is based was performed in an attempt to determine the application of the Sonic Test to the evaluation of stripping resistance in compacted bitumen-aggregate mixtures. Tests were conducted on beam specimens molded from materials the same as those used in the construction of a high-type bituminous concrete pavement. Two other accepted tests, the Immersion-Compression Test and the Visual Stripping Test, were used to obtain a comparison with results obtained by the Sonic Test. Three aggregates, gravel, limestone, and rhyolite, and one asphalt were used to show different degrees of stripping for the tests used. An asphalt bonding additive was used in one group of specimens evaluated by the Sonic Test. Another group of specimens included a different gradation to show the effect this had on the Sonic Test results.

MATERIALS AND METHOD

Materials used in this study included gravel from Lafayette, Indiana, limestone from Greencastle, Indiana, Massachusetts rhyolite, and 85-100 penetration asphalt cement obtained from the Standard Oil Company of Indiana. All three aggregates were processed to an "Indiana AH Type B Surface Course" gradation ($\frac{1}{2}$-inch maximum) (6) with the rhyolite also processed to a "Corps of Engineers' Surface Course" gradation ($\frac{1}{2}$-inch maximum) (7). When gravel was used in the beam specimens and cylindrical specimens, limestone was used for the fraction passing the number 100 sieve. Rhyolite used in similar specimens contained limestone for the fraction passing the $\frac{1}{2}$-inch sieve and retained on the 3/8-inch sieve. Asphalt content was 6.5 percent based on the total weight of the mixture for the beam specimens and cylindrical specimens. An asphalt bonding additive was used in one group of beam specimens made with rhyolite aggregate and the Indiana gradation. The two gradations used are given in Tables 1 and 2. Specific gravity and absorption values for the aggregates are presented in Table 3, and test properties for the asphalt are included in Table 4.

Immersion-Compression Test specimens (Figure 1) four inches in diameter and four inches high were sawed from the ends of ten-inch high cylinders molded using double-plunger compaction with 3,000 psi maintained for two minutes. All specimens were cured for 24 hours in an oven at a temperature of 140°F. Before curing and immersion in water, all specimens were placed on glass plates to prevent breakage or distortion. After curing, the bulk specific gravity was determined for each specimen. Compressive strengths were determined in accordance with the A.S.T.M. Method

of Test for Compressive Strength of Bituminous Mixtures (D1074-58T).

The water exposure used on the immersion-compression specimens and the beam specimens consisted of immersion in tap water with a pH of seven at a temperature of 140 $\pm$ 1.8°F. Periods of immersion were one, three, five, seven, and nine days.

As a check on inconsistant results obtained with immersion-compression specimens described above, A.S.T.M. Method of Test for Effect of Water on Cohesion of Compacted Bituminous Mixtures was made on all three aggregates with the Indiana gradation. The alternate procedure for immersion 24 hours at 140°F, was used with immersion in distilled water with a pH of five.

The stripping test followed the Provisional A.S.T.M. "Static Immersion Stripping Resistance Test" procedure with the exception of several changes to permit taking of photos and continued immersion for the same periods used in the Sonic Test and the Immersion-Compression Test. Visual estimation of the aggregate area remaining coated for the Stripping Test was made in the following manner: three observers made individual estimates of the area of the aggregate surface remaining coated for all three aggregates at the end of nine days immersion. These estimates were averaged and returned to the observers. Then each observer made individual estimates from the photos of the percentage of the area of each aggregate remaining coated for one, three, five, and seven days immersion.

Table 1

Gradation for AH Type B

Hot Asphaltic Concrete Surface Course

State Highway Commission of Indiana

Passing Sieve	Retained Sieve	Percent by Weight
1/2 inch	3/8 inch	9
3/8 inch	No 4	29
No 4	No 8	20
No 8	No 16	12
No 16	No 50	17
No 50	No 100	6
No 100	No 200	3
No 200	- - -	4

Table 2

Gradation for Bituminous-Aggregate Mix

Corps of Engineers' Surface Course

Passing Sieve	Retained Sieve	Percent by Weight
1/2 inch	3/8 inch	5
3/8 inch	No. 4	20
No. 4	No. 8	15
No. 8	No. 16	12
No. 16	No. 50	23
No. 50	No. 100	10
No. 100	No. 200	9
No. 200	- - -	6

Table 3

Physical Properties of Aggregates

Aggregate	ASTM Bulk Sp Gr	ASTM App Sp Gr	Eff Sp Gr*	Absorption, %
Massachusetts rhyolite	2.62	2.68	2.67	0.85
Greencastle limestone	2.63	2.71	2.67	1.39
Lafayette gravel	2.60	2.74	2.69	2.04

*See reference (9).

Table 4

Physical Properties of Asphalt

Penetration (100 gm 5 sec. 77°F) 1/100 cm	91
Specific Gravity, 77°F	1.021
Solubility in CCl_4, %	99.94
Ductility (77°F, 5 cm/sec) cm	150 +

Figure 1. - Cylindrical Mold and Specimens

SONIC APPARATUS AND TEST PROCEDURE

Sonic apparatus (Figure 2) used in this study consisted of a type 304-A Dumont cathode-ray oscillograph, a model 655 Jackson audio oscillator, a modified ST 104 Jensen speaker used as the driver, and a VM-1 Brush Vibromike used as the pickup. Equipment used to mold the beam specimens included the beam mold (Figure 3) and attachments for applying rolling action to the beam specimens (Figure 4). Ideas for the equipment used to apply rolling action to the beam specimens where obtained from reference (8).

Beam specimens twelve inches long by two and one-half inches thick by about two inches wide were molded using the following procedure: The mixture of aggregate and asphalt at a temperature of about 275°F was placed in the mold, spread uniformly throughout its length, and then compacted under a static load of 600 psi applied for one minute to the top and bottom faces of the specimen (Figure 5). Next, using the roller compaction attachment (Figure 4) with a load of 300 pounds per lineal inch across the beam, ten passes were applied to the top face of the specimen. Then a static load of 800 psi was applied to the top face of the beam specimen for two minutes. After molding, the specimens were placed on glass plates and cured for 24 hours in an oven at a temperature of 140°F. Next, the bulk specific gravity values were determined following the procedure described in part 4 of A.S.T.M. Test D1075-54.

Prior to testing, each specimen was cooled for two hours in a water bath at 40°F. The beam was then removed from the water, all the surface water wiped off, and placed on the stand with one side of the beam in contact with the driver (Figure 2). The driver was actuated by the oscillator

having a frequency range of 20 to 20,000 cycles per second. The Brush Vibromike used as the pickup unit would detect vibration of the beam specimen. The signal generated in the pickup was fed to the Y-plates of the oscillograph. As the output frequency of the oscillator to the driver was varied, the signal detected by the pickup fed to the Y-plates of the oscillograph would vary by the same amount. When the beam is vibrating at its fundamental frequency, the signal from the pickup fed to the oscillograph will register a trace with maximum amplitude. This frequency of vibration may then be read from the oscillator dial and recorded.

To make sure that the frequency determined above was the fundamental frequency, a check was made for existance of nodal points. These nodes should be located a distance of 0.224 L from either end of a beam with a length L, vibrating transversely in a free-free condition (5). This check was made by feeding the oscillator signal directly to the X-plates on the oscillograph in addition to feeding the signal to the driver. The signal detected by the pickup was fed to the Y-plates. When these signals were of the same frequency and in phase, a Lissajous circle was seen on the tube screen. After finding the frequency for maximum amplitude of the oscillograph trace, zero amplitude of vibration was shown on the Y-plates after moving the pickup to the theoretical location of a nodal point. On moving the pickup to each side of the nodal point, the Lissajous circle formed (Figure 2) showed inclinations in opposite directions indicating a reversal of direction of the vibrational movement on each side of the nodal point.

A relative modulus of elasticity may be obtained from the squares of the fundamental frequencies if the same beam is considered. Computation of the modulus of elasticity in this study followed the method described

by Bawa (3) and Yong (4). The following formula was used:

$$E = CWn^2$$

where: $C = 0.00323 \frac{\ell^3}{bt^3}$

E = Young's modulus of elasticity, psi

W = weight of beam, lb

n = fundamental frequency, cps

ℓ = length of beam, in

b = width of beam, in

t = thickness of beam, in

On completion of the Sonic Test for no immersion, the beam specimens were placed on glass plates, and subjected to water exposure by complete immersion in tap water at a temperature of 140°F. After each period of immersion, one, three, five, seven, and nine days, each specimen was cooled for two hours in a water bath at 40°F. The beam was then taken from this water bath, the glass plates removed, and the procedure described above for the Sonic Test was repeated.

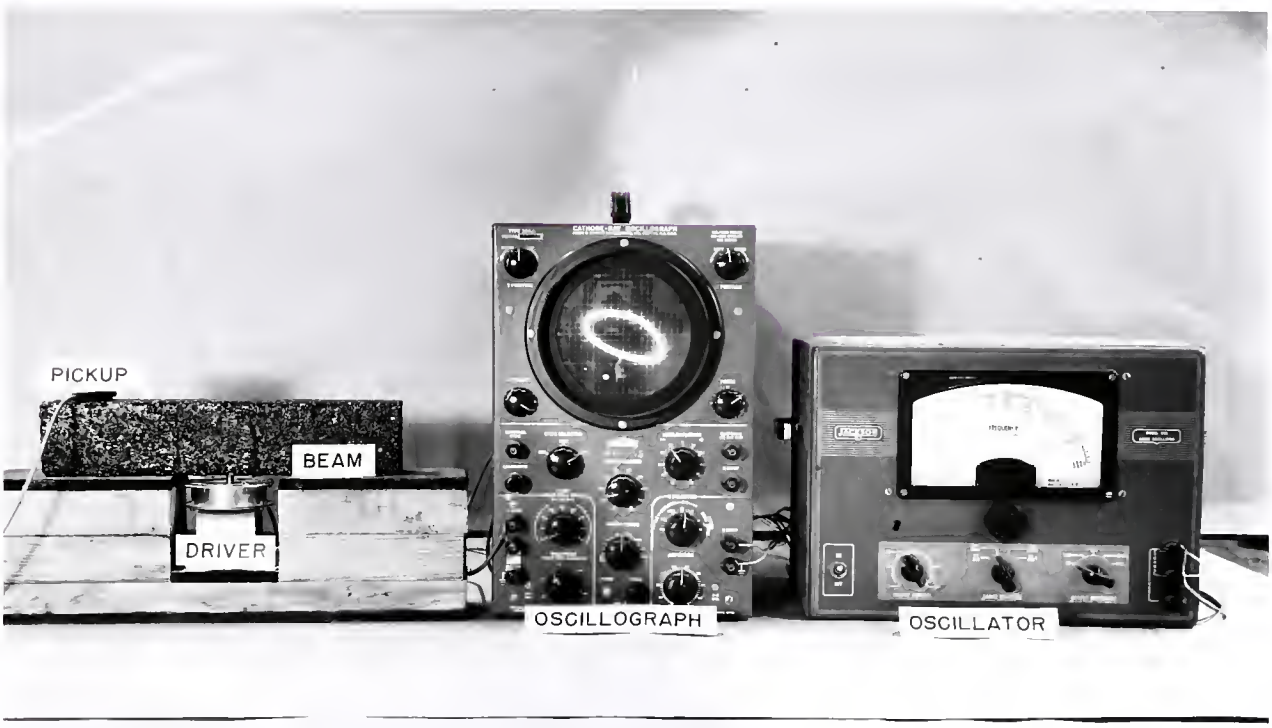

Figure 2. - Apparatus Used in Sonic Test of Beam Specimen.

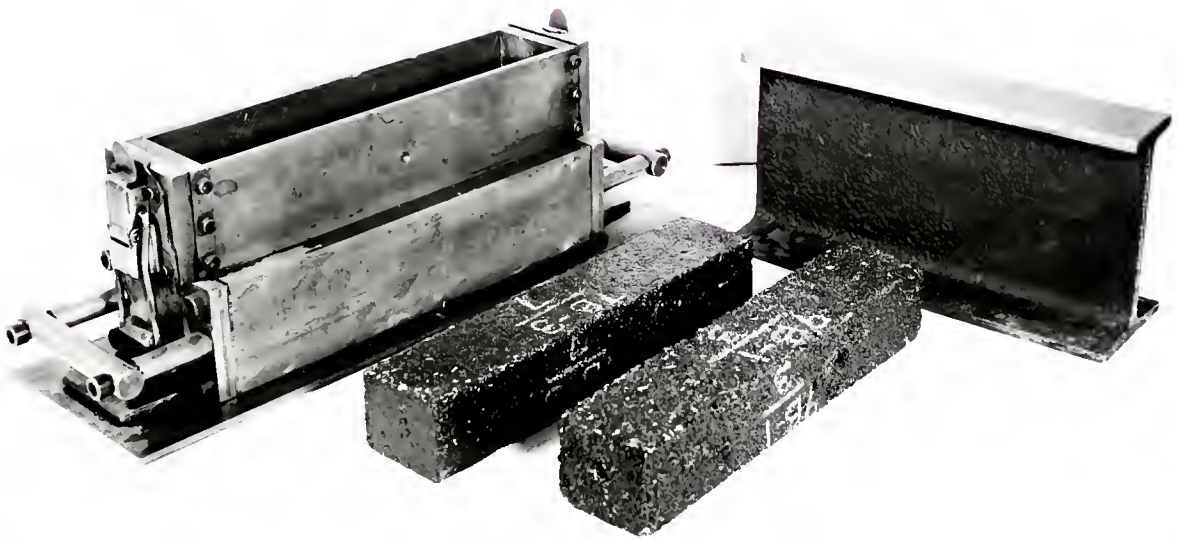

Figure 3. Beam mold and specimens.

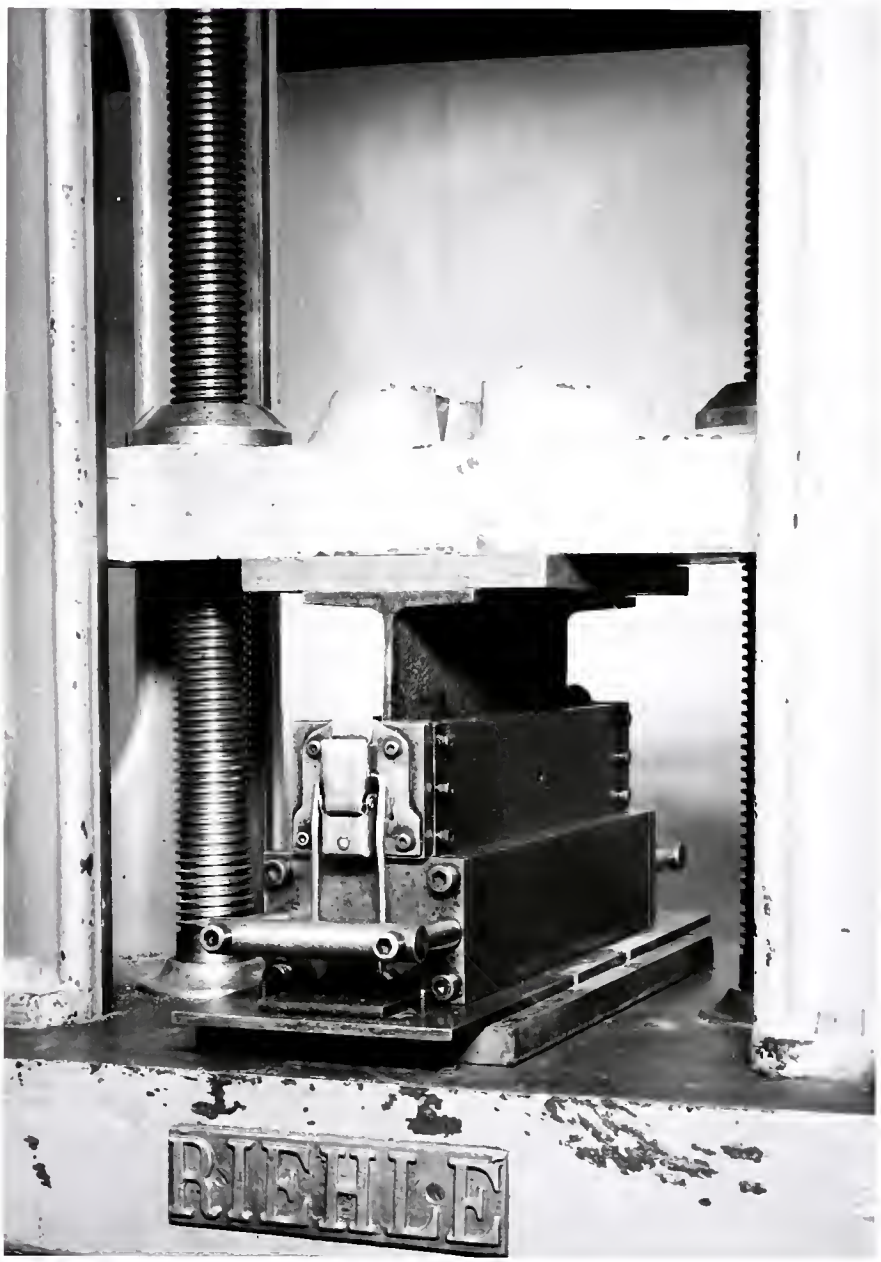

Figure 4. - Rolling Action Applied to Beam Specimen After Initial Static Compaction.

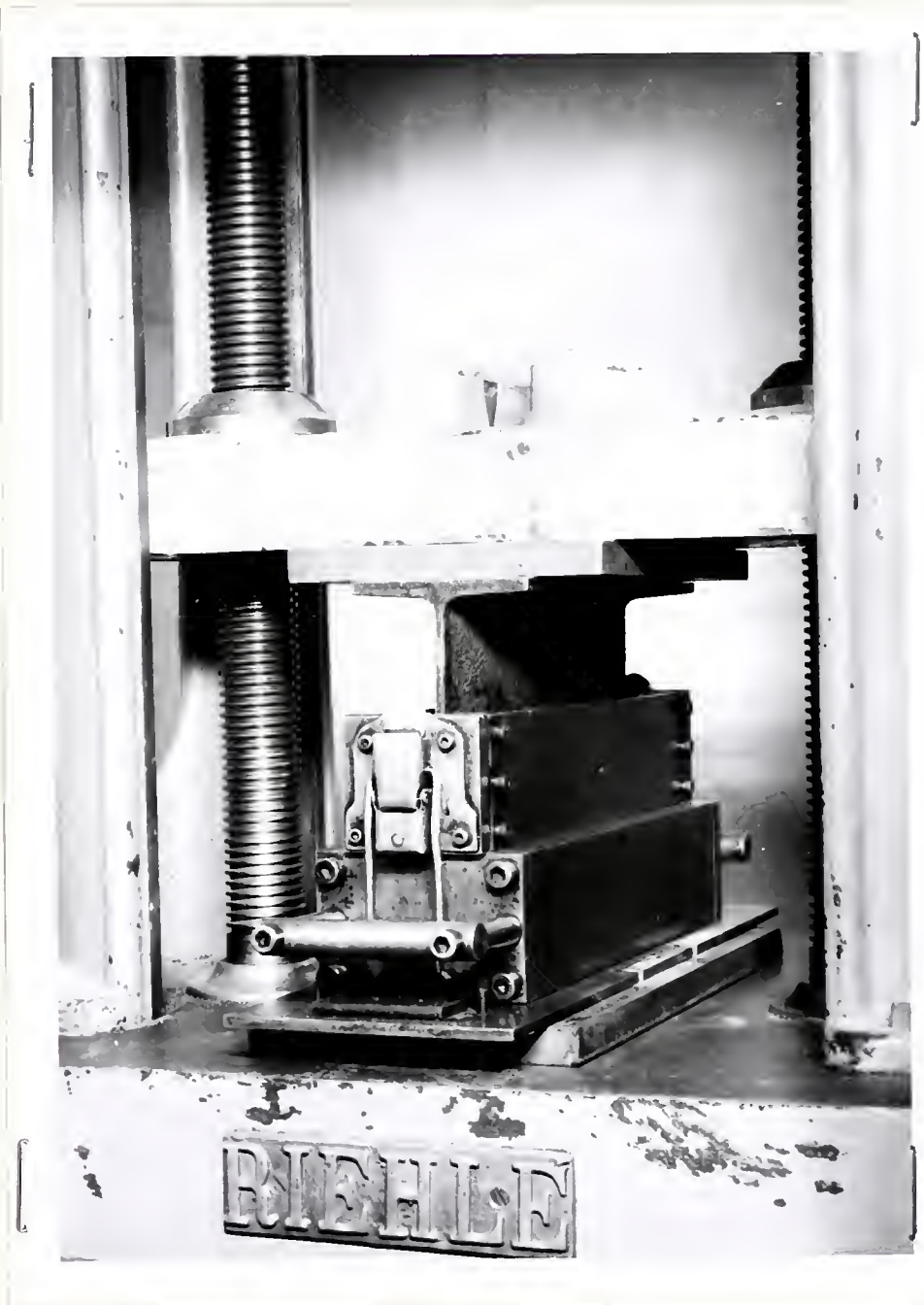

Figure 5. - Static Load Applied to Beam Specimen.

RESULTS

The results of this study include data for the evaluation of stripping resistance in compacted bituminous mixtures obtained by the Sonic Test, the Immersion-Compression Test, and the Static Immersion Stripping Resistance Test. Three different aggregates, a gravel, a limestone, and a rhyolite, combined with one asphalt (85-100 penetration) were used to show different degrees of stripping when subjected to immersion in water under prescribed conditions of temperature and time. All three aggregates were processed to the same Indiana gradation and combined with 6.5 percent asphalt. Rhyolite was also processed to a Corps of Engineers' gradation and combined with 6.5 percent asphalt to check the effect of gradation on the Sonic Test results. An asphalt bonding additive was used with the rhyolite in the Indiana gradation to find out what effect this would have on the results obtained by the Sonic Test. Data for these tests are presented in this section.

The Sonic Test results for the three aggregates using the Indiana gradation are shown in Figure 6. The percent retained modulus of elasticity is plotted against days of immersion in water at 140°F. Numerical values plotted on this Figure are listed in Table 1 which includes the average Sonic modulus values for the group of four beams. Information about the specimens is listed in Tables 10, 11, and 12. Results showing the effect of a different gradation and the effect of the addition of an asphalt bonding additive are shown in Figure 7. Table 6 and part of Table 5 on the rhyolite stone include the numerical values for Figure 7. Specimen data are listed in Tables 12, 13, and 14.

The Immersion-Compression Test results for the three aggregates

using the Indiana gradation are shown in Figure 8. The percent total strength retained is plotted against days of immersion in water at 140°F. The numerical values plotted in Figure 8 are given in Table 7. Data about the Immersion-Compression Test specimens are listed in Tables 15, 16, and 17. The A.S.T.M. Standard Method of Test for Effect of Water on Cohesion of Compacted Bituminous Mixtures was applied to all three aggregates as a check on results obtained using four-inch specimens sawed from each end of molded ten-inch cylinders. Data on specimens prepared and tested by the standard method are listed in Table 8.

Results from the Static Immersion Stripping Resistance Test using the three different aggregates are shown in Figure 9. The percent aggregate area remaining coated is plotted against days of immersion in water at 140°F. Numerical values for Figure 9 are listed in Table 9 including individual estimates by the observers.

IMMERSION PERIOD
VS.
RETAINED MODULUS OF ELASTICITY
USING
SONIC TEST

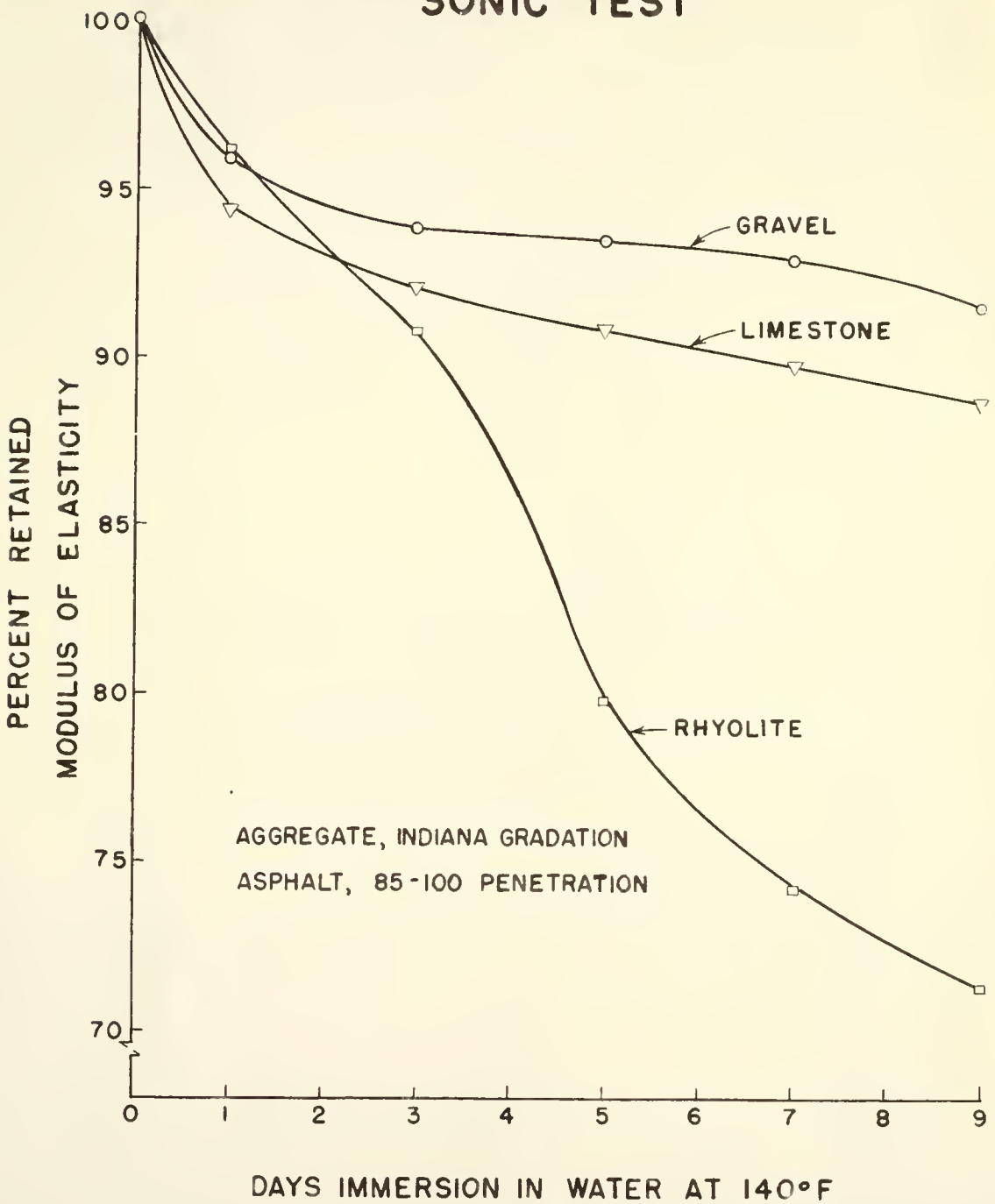

FIG. 6

Table 5

Sonic Test Results

Indiana AH Type B Surface Course

Days Immersion in Water at 140°F	Av of 4 beams, Sonic Modulus x 10^6 psi	% Retained Sonic Modulus
Lafayette Gravel		
0	2.95	100.0
1	2.83	95.9
3	2.77	93.8
5	2.76	93.5
7	2.74	92.9
9	2.70	91.5
Greencastle Limestone		
0	3.29	100.0
1	3.10	94.3
3	3.03	92.1
5	2.99	90.8
7	2.95	89.7
9	2.92	88.7
Massachusetts Rhyolite		
0	2.09	100.0
1	2.01	96.2
3	1.90	90.8
5	1.67	79.8
7	1.55	74.2
9	1.49	71.3

IMMERSION PERIOD
VS.
RETAINED MODULUS OF ELASTICITY
USING
SONIC TEST

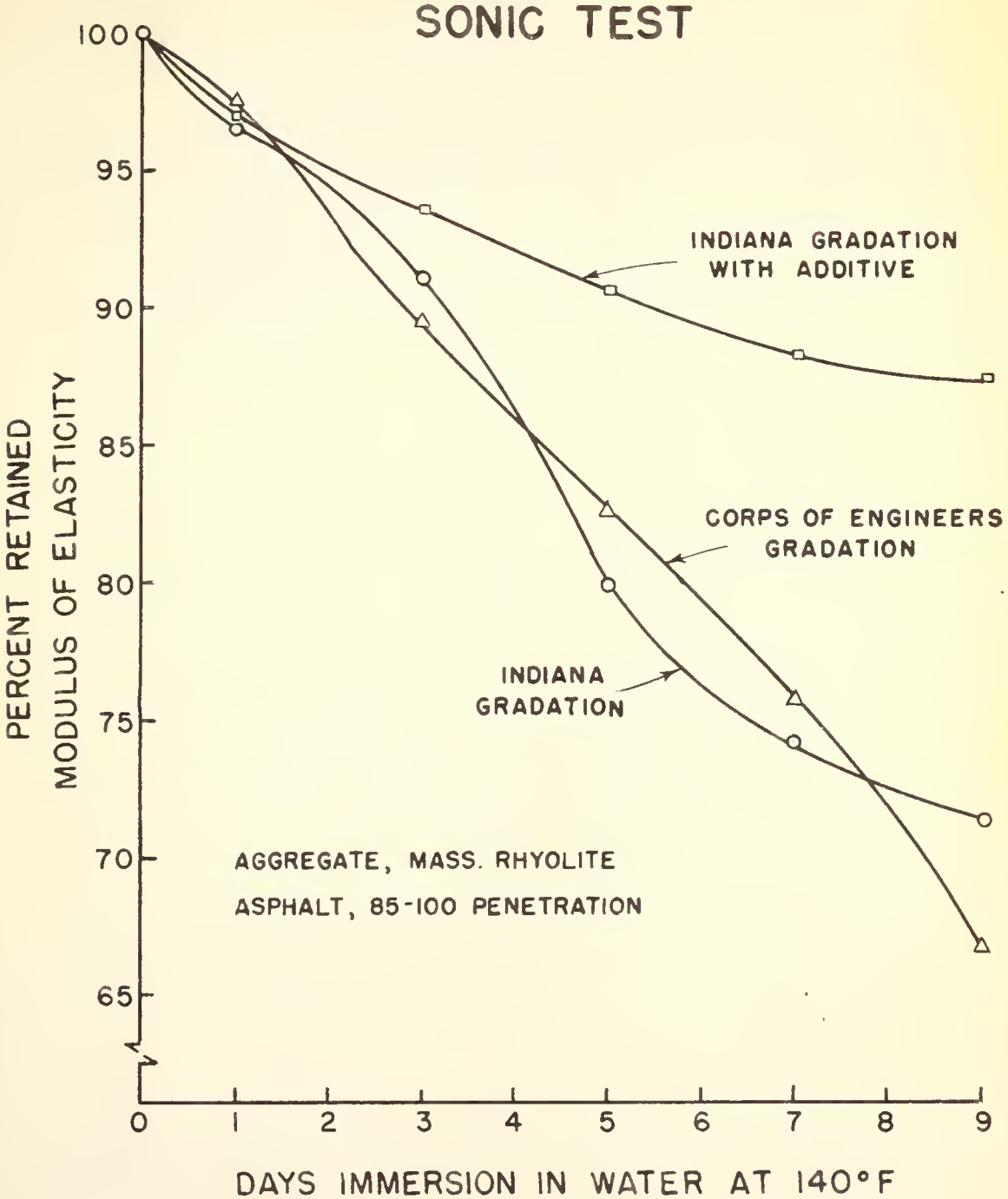

FIG. [redacted] 7

Table 6

Sonic Test Results

Massachusetts Rhyolite

Days Immersion in Water at 140°F	Av Sonic Modulus x 10^6 psi, 4 beams	% Retained Sonic Modulus
Indiana AH Type B Surface Course with an Asphalt Additive		
0	2.10	100.0
1	2.03	96.7
3	1.96	93.3
5	1.90	90.4
7	1.85	88.1
9	1.83	87.2
Corps of Engineers' Surface Course		
0	2.80	100.0
1	2.72	97.2
3	2.43	89.2
5	2.31	82.5
7	2.12	75.7
9	1.87	66.8

IMMERSION PERIOD
VS.
PERCENT TOTAL STRENGTH RETAINED
USING
IMMERSION-COMPRESSION TEST

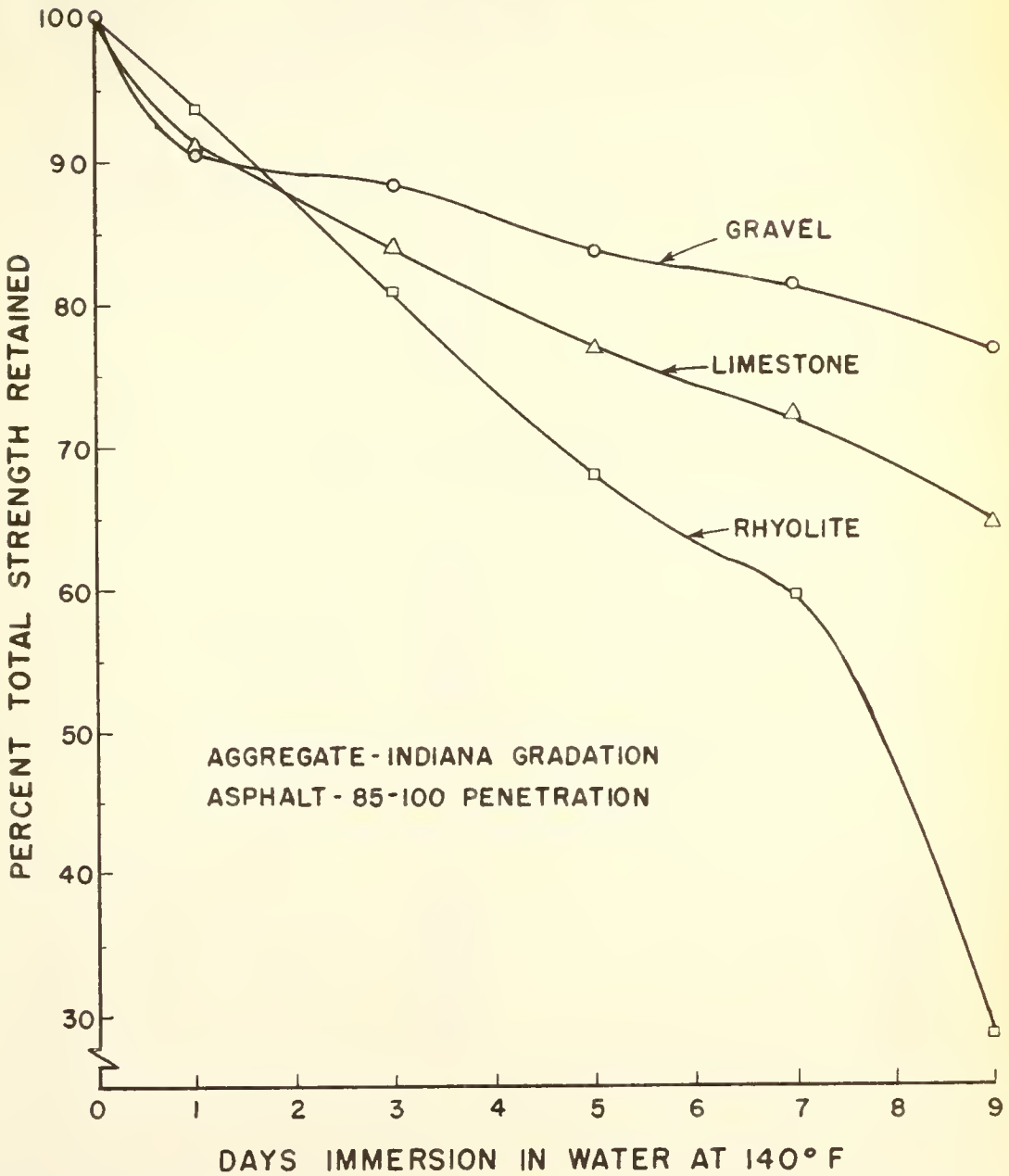

FIG. 8

Table 7

Immersion-Compression Test Results

Indiana AH Type B Surface Course

Days Immersion in Water at 140°F	Av Comp Strength 3 Specimens, lb	% Retained Strength
	Lafayette Gravel	
0	2958	100.0
1	2688	90.3
3	2614	88.3
5	2468	83.5
7	2418	81.7
9	2277	76.9
	Greencastle Limestone	
0	4346	100.0
1	3947	90.8
3	3654	84.0
5	3338	76.8
7	3122	72.0
9	2797	64.3
	Massachusetts Rhyolite	
0	3236	100.0
1	3020	93.3
3	2615	80.8
5	2197	67.8
7	1928	59.6
9	922	28.5

Table 8

Immersion-Compression Test Results

A.S.T.M. Test D1075-54

Indiana AH Type B Surface Course

Spec #	Bulk Sp Gr	Av Bulk Sp Gr	Voids by App Sp Gr	Voids by Eff Sp Gr	Days Immersion at 140°F	Comp Strength, lb	Av Comp Strength, lb	% Ret Strength
			Lafayette Gravel					
2	2.38		3.4	2.1	0	2615		
4	2.38	2.39	3.2	1.9	0	2970	2762	100.0
6	2.38		3.1	1.8	0	2700		
1	2.38		3.4	2.1	1	2505		
3	2.38	2.38	3.4	2.1	1	2885	2777	100.3
5	2.38		3.3	2.0	1	2940		
			Greencastle Limestone					
2	2.40		1.7	0.7	0	4473		
5	2.41	2.40	1.2	0.3	0	5050	5141	100.0
6	2.40		1.6	0.6	0	6000		
1	2.40		1.5	0.5	1	4165		
3	2.40	2.40	1.5	0.5	1	4510	4325	84.2
4	2.40		1.5	0.6	1	4300		

(Table continued on next page)

Table 8 (Cont.)

Immersion-Compression Test Results

A.S.T.M. Test D1075-54

Indiana AH Type B Surface Course

Spec #	Bulk Sp Gr	Av Bulk Sp Gr	Voids by App Sp Gr	Voids By Eff Sp Gr	Days Immersion at 140°F	Comp Strength, lb	Av Comp Strength, lb	% Ret Strength
			Massachusetts Rhyolite					
1	2.22		7.6	7.5	0	3400		
5	2.22	2.22	7.0	6.9	0	3340	3321	100.0
6	2.23		7.2	7.2	0	3222		
2	2.22		7.4	7.4	1	2790		
3	2.23	2.23	7.3	7.3	1	2890	2785	83.8
4	2.23		7.5	7.5	1	2675		

IMMERSION PERIOD
VS.
PERCENT AREA AGGREGATE REMAINING COATED
USING
STRIPPING RESISTANCE TEST

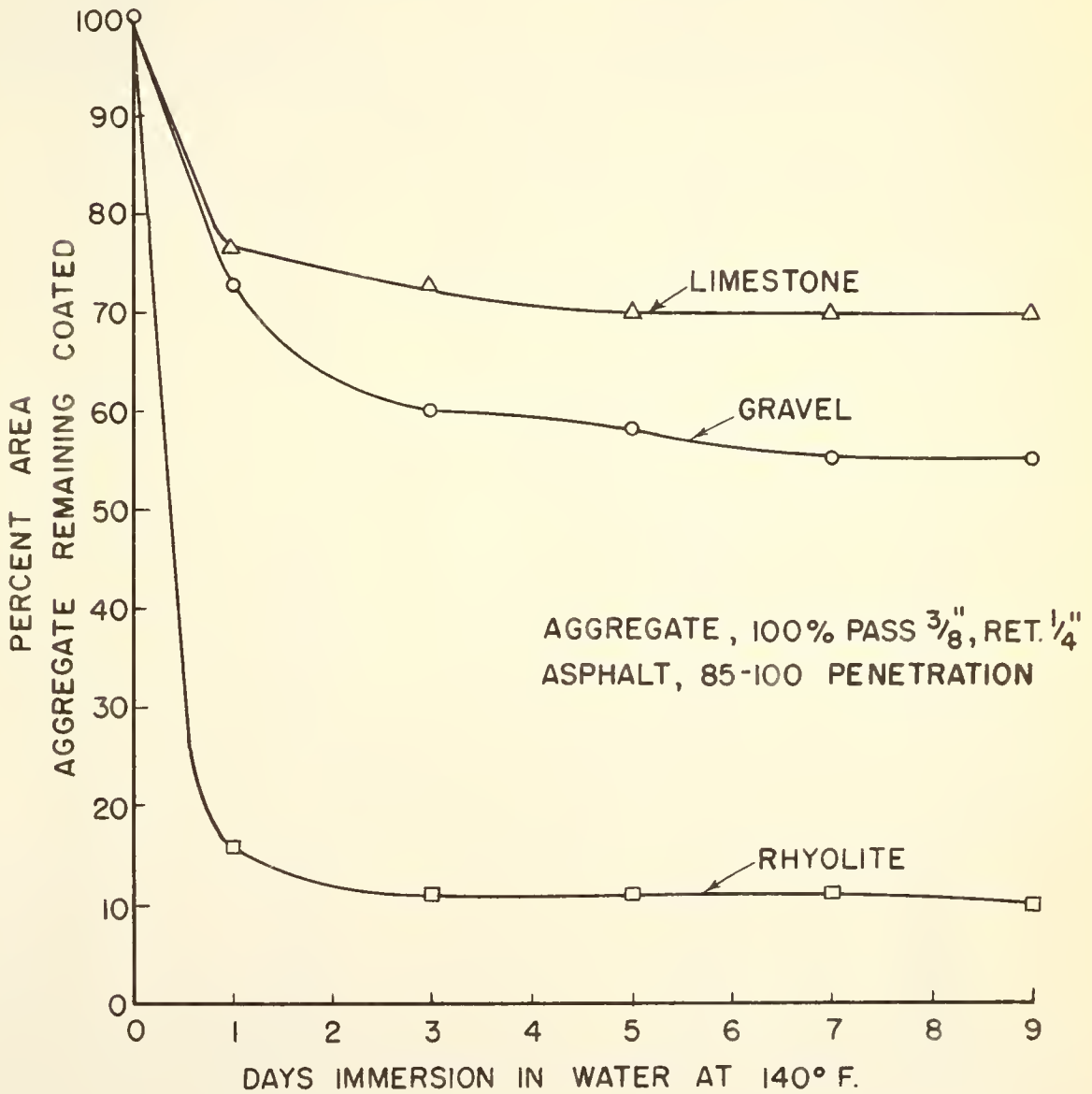

FIG. 9

Table 9

Static Immersion Stripping Resistance Test Results

Days Immersion at 140°F	Estimated Percent Area Aggregate Remaining Coated			
	1st Observer	2nd Observer	3rd Observer	Average of 3 Observers
Lafayette Gravel				
0	100	100	100	100
1	70	80	70	73
3	65	60	55	60
5	60	60	55	58
7	55	55	55	55
9	55	55	55	55
Greencastle Limestone				
0	100	100	100	100
1	80	80	70	77
3	75	75	70	73
5	70	70	70	70
7	70	70	70	70
9	70	70	70	70
Massachusetts Rhyolite				
0	100	100	100	100
1	20	20	10	17
3	10	15	10	12
5	10	15	10	12
7	10	15	10	12
9	10	10	10	10

Table 10

Sonic Test Specimens

Indiana AH Type B Surface Course

Lafayette Gravel

Beam Specimen #	Weight, lb (w)	Breadth, in (b)	Bulk Sp Gr	% Voids by App Sp Gr Agg	% Voids by Eff Sp Gr Agg	Days Immersion in Water at 140°F	Fundamental Frequency Vibration, cps	Sonic Modulus x 10^6 psi
1	5.35	2.05	2.42	2.3	1.0	0	1790	2.98
						1	1770	2.92
						3	1750	2.85
						5	1740	2.82
						7	1730	2.79
						9	1720	2.76
3	5.35	2.03	2.40	2.4	1.1	0	1750	2.87
						1	1710	2.74
						3	1680	2.65
						5	1680	2.65
						7	1670	2.62
						9	1660	2.59
4	5.32	2.03	2.42	2.1	0.8	0	1770	2.92
						1	1760	2.89
						3	1750	2.86
						5	1750	2.86
						7	1740	2.83
						9	1730	2.79
5	5.30	2.02	2.42	2.8	1.5	0	1800	3.03
						1	1720	2.76
						3	1710	2.73
						5	1710	2.73
						7	1700	2.70
						9	1690	2.67

Sonic Test Specimens

Indiana AM Type B Surface Course

Greencastle Limestone

Beam Specimen #	Weight, lb (w)	Breadth, in (b)	Bulk Sp Gr	% Voids by App Sp Gr Agg	% Voids by Eff Sp Gr Agg	Days Immersion in Water at 140°F	Fundamental Frequency Vibration, cps	Sonic Modulus x 10^6 psi
7	5.33	2.02	2.42	1.0	0.1	0	1860	3.35
						1	1850	3.31
						3	1815	3.09
						5	1800	3.04
						7	1790	3.01
						9	1780	2.98
8	5.39	2.09	2.42	0.3	0.0	0	1880	3.24
						1	1820	3.04
						3	1800	2.98
						5	1790	2.94
						7	1775	2.89
						9	1760	2.84
9	5.46	2.09	2.41	1.0	0.0	0	1890	3.34
						1	1830	3.13
						3	1820	3.09
						5	1810	3.06
						7	1800	3.03
						9	1790	3.00
10	5.41	2.11	2.40	1.5	0.5	0	1880	3.22
						1	1820	3.02
						3	1800	2.96
						5	1790	2.93
						7	1780	2.89
						9	1770	2.86

Table 12

Sonic Test Specimens

Indiana AH Type B Surface Course

Massachusetts Rhyolite

Beam Specimen #	Weight, lb (w)	Breadth, in (b)	Bulk Sp Gr	% Voids by App Sp Gr Agg	% Voids by Eff Sp Gr Agg	Days Immersion in Water at 140°F	Fundamental Frequency Vibration, cps	Sonic Modulus x 10^6 psi
1	5.44	2.27	2.26	6.0	6.0	0	1570	2.10
						1	1540	2.02
						3	1520	1.97
						5	1460	1.87
						7	1380	1.62
						9	1350	1.56
3	5.47	2.28	2.26	6.1	6.1	0	1570	2.11
						1	1530	2.00
						3	1480	1.87
						5	1350	1.56
						7	1320	1.46
						9	1270	1.38
4	5.24	2.17	2.26	6.1	6.0	0	1560	2.09
						1	1530	2.01
						3	1480	1.88
						5	1340	1.54
						7	1310	1.47
						9	1260	1.41
5	5.41	2.26	2.26	6.0	6.0	0	1560	2.07
						1	1530	2.00
						3	1480	1.87
						5	1420	1.72
						7	1400	1.67
						9	1370	1.60

Table 13

Sonic Test Specimens

Corps of Engineers Surface Course

Massachusetts Rhyolite

Beam Specimen #	Weight, lb (w)	Breadth, in (b)	Bulk Sp Gr	% Voids by App Sp Gr Agg	% Voids by Eff Sp Gr Agg	Days Immersion in Water at 140°F	Fundamental Frequency Vibration cps	Sonic Modulus x 10^6 psi
6	5.46	2.20	2.32	3.5	3.5	0	1790	2.84
						1	1770	2.77
						3	1740	2.68
						5	1725	2.63
						7	1700	2.56
						9	1640	2.38
7	5.41	2.16	2.32	3.5	3.0	0	1780	2.83
						1	1770	2.79
						3	1720	2.64
						5	1700	2.58
						7	1660	2.45
						9	1540	2.12
9	5.42	2.18	2.32	3.8	3.7	0	1800	2.87
						1	1780	2.81
						3	1720	2.62
						5	1685	2.52
						7	1530	2.07
						9	1370	1.66
10	5.39	2.19	2.30	5.1	5.1	0	1740	2.65
						1	1700	2.53
						3	1420	1.77
						5	1310	1.50
						7	1275	1.42
						9	1230	1.32

Table 14

Sonic Test Specimens

Indiana AH Type B Surface Course

Massachusetts Rhyolite with Asphalt Additive

Beam Specimen #	Weight, lb (w)	Breadth, in (b)	Bulk Sp Gr	% Voids by App Sp Gr Agg	% Voids by Eff Sp Gr Agg	Days Immersion in Water at 140°F	Fundamental Frequency Vibration, cps	Sonic Modulus x 10^6 psi
14	5.33	2.28	2.21	3.1	7.8	0	1580	2.08
						1	1550	2.00
						3	1520	1.93
						5	1490	1.85
						7	1450	1.75
						9	1430	1.71
16	5.31	2.28	2.23	7.7	7.4	0	1580	2.07
						1	1550	2.00
						3	1530	1.95
						5	1500	1.87
						7	1500	1.87
						9	1500	1.87
17	5.40	2.26	2.23	7.5	7.2	0	1590	2.16
						1	1570	2.10
						3	1540	2.02
						5	1520	1.97
						7	1500	1.92
						9	1490	1.89
18	5.46	2.34	2.20	8.4	8.1	0	1590	2.10
						1	1560	2.03
						3	1530	1.95
						5	1510	1.90
						7	1500	1.87
						9	1500	1.87

Table A5

Immersion-Compression Specimens

Indiana AH Type D Surface Course

Lafayette Gravel

Spec #	Bulk Sp Gr	Av Bulk Sp Gr	Voids by App Sp Gr	Voids by Eff Sp Gr	Days Immersion at 140°F	Comp Strength, lb	Av Comp Strength, lb	% Ret Strength
2	2.40		2.7	1.4	0	2943		
6	2.39	2.39	3.0	1.7	0	2870	2958	100
1	2.39		2.8	1.5	0	3060		
5	2.39		3.0	1.6	1	2795		
4	2.37	2.39	3.5	2.2	1	2565	2688	90.3
23	2.42		1.2	0.1	1	2705		
7	2.39		3.1	1.8	3	2628		
3	2.39	2.40	2.9	1.5	3	2650	2614	88.3
29	2.41		1.8	0.4	3	2565		
10	2.39		3.1	1.6	5	2438		
21	2.41	2.40	2.3	0.7	5	2415	2468	83.5
9	2.39		2.6	1.3	5	2550		
14	2.40		2.5	1.2	7	2530		
18	2.39	2.40	2.8	1.3	7	2350	2418	81.7
27	2.42		2.3	0.9	7	2373		
12	2.39		3.2	2.0	9	2345		
15	2.39	2.39	3.4	2.1	9	2165	2277	76.9
20	2.42		2.0	0.7	9	2320		

Table 16

Immersion-Compression Specimens

Indiana AH Type B Surface Course

Greencastle Limestone

Spec #	Bulk Sp Gr	Av Bulk Sp Gr	Voids by App Sp Gr	Voids by Eff Sp Gr	Days Immersion at 140°F	Comp Strength, lb	Av Comp Strength, lb	% Ret. Strength
4	2.39		2.0	1.1	0	3950		
5	2.40	2.40	1.5	0.5	0	4472	4346	100
21	2.41		1.3	0.4	0	4615		
19	2.40		1.4	0.5	1	3899		
20	2.40	2.40	1.5	0.5	1	3875	3947	90.8
22	2.41		0.9	0.0	1	4115		
17	2.41		1.2	0.2	3	3650		
18	2.41	2.41	1.4	0.5	3	3610	3644	84.0
24	2.41		0.9	0.0	3	3702		
8	2.39		1.9	1.0	5	3390		
12	2.40	2.40	1.3	0.3	5	3325	3338	76.8
14	2.40		1.4	0.4	5	3300		
9	2.40		1.6	0.7	7	3265		
10	2.39	2.40	1.9	1.0	7	3060	3122	72.0
13	2.40		1.8	0.8	7	3040		
6	2.40		1.7	0.7	9	2790		
7	2.40	2.40	1.7	0.7	9	3060	2797	64.3
11	2.39		2.1	1.1	9	2540		

Table 17

Immersion-Compression Specimens

Indiana AH Type b Surface Course

Massachusetts Rhyolite

Spec #	Bulk Sp Gr	Av Bulk Sp Gr	Voids by App Sp Gr	Voids by Eff Sp Gr	Days Immersion at 140°F	Comp Strength lb	Av Comp Strength, lb	% Ret Strength
10	2.27		5.4	5.4	0	3277		
9	2.26	2.27	6.1	6.1	0	3205	3236	100
15	2.29		4.9	4.9	0	3225		
1	2.24		6.1	6.1	1	2945		
11	2.27	2.26	5.4	5.4	1	3150	3020	93.3
12	2.27		5.9	5.9	1	2965		
2	2.27		6.0	6.0	3	2205		
20	2.29	2.28	4.9	4.8	3	2800	2615	80.8
25	2.28		5.2	5.1	3	2840		
16	2.28		5.1	5.0	5	2174		
19	2.27	2.28	5.4	5.4	5	2223	2197	67.8
14	2.27		5.6	5.6	5	2192		
4	2.27		5.9	5.9	7	2158		
30	2.29	2.28	4.8	4.8	7	1615	1928	59.6
27	2.28		5.1	5.1	7	2010		
7	2.26		5.6	5.6	9	825		
8	2.26	2.27	6.1	6.1	9	962	922	28.5
13	2.27		5.1	5.1	9	978		

DISCUSSION OF RESULTS

This discussion (a) describes the results obtained using the Sonic Test, (b) compares them with results using the Immersion-Compression Test, (c) compares them with results using the Static Immersion Stripping Resistance Test, and (d) discusses the advantages of the Sonic Test with respect to other tests.

Sonic Test

The stripping qualities of the aggregates as reflected in the Indiana AH Type B surface course mixtures by means of the Sonic Test are shown graphically in Figure 6 on the basis of percent retained modulus of elasticity versus days immersion in water at 140°F. Plotted results for the mixtures in which the three aggregates were used show a decrease in retained modulus of elasticity throughout the period of immersion Initially this decrease is rapid for all three mixtures. After about one day of immersion, the gravel and limestone curves continue with a much smaller change in modulus of elasticity for the additional periods of immersion. The rhyolite curve continues at about the same slope for the additional periods of immersion. With the more dense Corps of Engineers' gradation, about the same decrease in retained modulus of elasticity was obtained for the rhyolite aggregate (Figure 7) as is shown with the Indiana gradation.

A lithological count of the gravel revealed that it contained about 53 percent limestone. Since all the material passing the Number 100 sieve used in the gravel specimens was limestone, the final limestone content of the gravel specimens was about 57 percent. This would indicate why results observed for the gravel are more nearly like those for the limestone than those obtained for the rhyolite.

On completion of one day immersion, the mixture containing hydrophilic rhyolite had a higher retained modulus of elasticity than either the gravel or the limestone mixtures (Figure 6). This would indicate that the true stripping qualities of the aggregates are not revealed by the Sonic Test until after one day immersion with the gradation, asphalt content, density, and exposure conditions used in this study. Continued immersion for 11 to 12 days results in complete failure of the rhyolite specimens as shown in Figure 10.

An indication of the effect of gradation on results for the Sonic Test is shown in Figure 7. The average values for one group of four specimens made with the Indiana gradation is compared to the average values for another group of four specimens made with the Corps of Engineers' gradation, other conditions remaining the same. Plotted results of both groups follow about the same general slope.

Compared to the same rhyolite mixture (Indiana gradation) with no asphalt additive, the additive improved the percent retained modulus of elasticity at all periods of immersion after one day as shown in Figure 7. The asphalt bonding additive used with the rhyolite improved its stripping resistance to the extent where it was comparable to the limestone with no additive. Again, as was the case without additive, the stripping qualities of the rhyolite were not shown until after more than one day immersion.

An examination of the fundamental frequency and sonic modulus data for duplicate beam specimens included in Tables 10, 11, 12, 13, and 14, reveals that substantially the same results were obtained for duplicate tests in each case. In this study, an almost identical result would have been obtained in any case if only one beam specimen had been used to obtain

Figure 10. - Failure of a Rhyolite Beam Specimen After Continued Immersion in Water at 140°F.

the test result rather than the average of four such specimens. However, we would advocate the testing of duplicate specimens. This is cited to indicate excellent reproducibility for the Sonic Test as used in this study. This fact, coupled with the fact that the Sonic Test is a non-destructive one, makes it possible to obtain a maximum of information with a minimum number of specimens when the Sonic Test is used.

Comparison of Sonic Test with Immersion-Compression Test

The stripping qualities of the aggregates as determined by the Immersion-Compression Test are shown graphically in Figure 8 on the basis of percent total strength retained versus days immersion in water at 140°F. After one day immersion, the stripping qualities of the rhyolite were not established. This is in agreement with the Sonic Test results (Figure 6). More than two days are required for either test to show the strongly hydrophilic character of the rhyolite. Continued immersion of the gravel and limestone specimens showed a smaller change in percent strength than is shown by the rhyolite specimens. For mixtures containing the same aggregates, the Sonic Test showed, qualitatively, a similar drop in percent retained modulus of elasticity as shown by the drop in percent total strength retained in the Immersion-Compression Test. Continued immersion of the Immersion-Compression rhyolite specimens for about ten days resulted in complete failure as shown in Figure 11. The decrease in percent retained modulus of elasticity for all aggregate mixtures using the Sonic Test numerically was not as great as the decrease in percent total strength retained for similar mixtures tested by the Immersion-Compression Test.

Some specimens used in the Immersion-Compression Test showed a

Figure 11. - Failure of a Rhyolite Immersion-Compression Specimen After Continued Immersion in Water at 140°F.

higher retained strength after three days immersion than some other specimens did after one day immersion (Table 15). In an attempt to find out if the method of molding ten-inch cylinders and sawing a four-inch specimen from each end was the reason for these discrepancies, a complete set of six specimens was prepared for each aggregate following the requirements for the A.S.T.M. Test D1074-54. The results of tests on these molded four-inch specimens showed the same inconsistencies in total retained strength between specimens subjected to no immersion and one day immersion (Table 8) as was obtained using four-inch specimens sawed from the ends of ten-inch cylinders.

An examination of the compressive strength data in Tables 15, 16, and 17 for duplicate Immersion-Compression Test specimens reveals that it was difficult to obtain consistent results and accounts for the fact that the standard test procedure requires the molding of six specimens of any one mixture for test. This is in direct contrast to the Sonic Test.

Comparison of Sonic Test with Visual Stripping Test

The stripping qualities of the three aggregates using the Static Immersion Stripping Test are shown graphically in Figure 9 on the basis of percent aggregate area remaining coated versus days immersion in water at 140°F. All three coated aggregates showed a sharp decrease in percent aggregate area remaining coated within the first day of immersion. After one day immersion the area remaining coated decreased very little from the one-day value in any case. The hydrophilic nature of the rhyolite is shown by a much greater initial drop in percent aggregate area remaining coated than occurred with either the gravel or limestone. The limestone showed the more area remaining coated when compared to the gravel by the

Visual Stripping Test. Two major reasons for expecting the difference in results from the Static Immersion Stripping Resistance Test as compared with the Sonic Test results and the Immersion-Compression Test results are the following: First, only one size fraction of the whole aggregate is selected for the test. Second, the coated aggregate as immersed in the water is in a loose uncompacted form.

Advantage of Sonic Test

In this study, the comparison of results from the three different methods of test illustrates definite advantages for the Sonic Test in conducting a test of the stripping qualities of a particular aggregate and asphalt.

First, the Sonic Test is performed on beam specimens molded from the bituminous mixture as it would be used in the field. This bituminous mixture has the same aggregate, filler, and bituminous material in the proportions used for actual construction and is compacted in a manner designed to simulate field compaction. It would be expected that the test would be sensitive to variations in the aggregate, filler, asphalt bonding additive, or other factors.

Second, the beam specimens can be used for repeated exposure cycles, the same beam being tested on completion of each cycle. This procedure eliminates errors caused by duplicate specimens having different characteristics as experienced in the Immersion-Compression Test. The deterioration of the same specimen is observed on completion of each cycle of exposure. With no need for a large number of duplicate specimens, this saves time and work normally involved in preparing the additional specimens.

Third, a quantitative measurement of stripping or loss in adhesion is obtained for each specimen based on the actual deterioration of the compacted bituminous mixture. The numerical values are unaffected by the personal factor involved in the estimation systems as used in several stripping tests.

CONCLUSIONS

This laboratory study was initiated for the purpose of determining the usefulness of the Sonic Test in evaluating the stripping qualities of compacted bitumen-aggregate mixtures containing penetration grade asphalts. Sonic Test results are compared with the results of two other tests using three different aggregates, one asphalt, two gradations, and with other conditions as much alike as possible. With this in mind, and within the limits of the materials and methods employed, the following conclusions seem justified:

1. The Sonic Test gave results that revealed the stripping qualities of the aggregates employed as well as or better than either the Immersion-Compression Test or the Visual Stripping Resistance Test. Since specimens for the Sonic Test contained materials of the same kind, gradation, and proportions compacted in a similar manner as would be used in actual field construction, the Sonic Test has inherent advantages over both the Immersion-Compression Test and the Visual Stripping Test.

2. The Sonic Test permitted observation of progressive stripping on the same beam specimens. In the Immersion-Compression Test additional specimens are required in order to observe deterioration of the specimens at various periods of exposure. Use of these additional specimens for the Immersion-Compression Test brought inconsistant results, some specimens showing a greater compressive strength for the later stages of exposure than other specimens did for less exposure.

3. Use of the Sonic Test permits a comparison of stripping qualities for different aggregates and asphalts using beam specimens molded follow-

ing the same procedure and exposed to the same exposure conditions for various periods of exposure. One group of four specimens will more than satisfy specimen requirements for each mixture. By this method, an aggregate and asphalt with a known record of field performance may be compared with another aggregate and asphalt with an unknown record of stripping performance.

4. The Sonic Test appears to have application in evaluating whether the stripping tendency of a specific aggregate or bitumen might be improved by the use of anti-stripping additives. On this basis it seems feasible to use the Sonic Test in checking the effectiveness of different anti-stripping additives in reducing stripping in a particular bituminous mixture.

5. The compaction procedure used in molding the beam specimens gave densities comparable to those densities obtained using the double-plunger method. The rolling action applied to the beam specimens during molding would seem to give particle orientation similar to that obtained in field construction following rolling. Therefore, it is indicated that the Sonic Test might produce laboratory results that would correlate well with results in the field. However, this conclusion is implied because field evaluation of the mixtures studied in the laboratory were not made. Also, it is not to be deduced from these data that aggregates showing inferior stripping resistance by laboratory test will necessarily produce unsatisfactory mixtures from a service viewpoint.

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